Thermodynamics One

Semester Projects

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Preface

Chapter 1

Stadium Roof

Estimate the energy requirements for the HVAC (heating, ventilation, and air-conditioning) system serving a very large indoor stadium. I often described the project in terms of adding a roof to Bryant-Denny Stadium, but any stadium or similar structure would suffice. Consider the Superdome in New Orleans: its interior volume is approximately 3,500,000 m^3. Be sure to choose a structure that does not exist. For example, imagining Bryant-Denny with a roof is a great project, whereas calculating the energy needs of the Superdome is not.

1.1 Human Comfort

Humans indoors find comfort in relatively narrow ranges of temperature and relative humidity, depending on season. Acheiving and maintaining a comfortable environment can an expensive undertaking. For easy proof, look at August and February utility bills. Expeditures related to HVAC make up a very large portion of worldwide energy consumption. Efficiently maintaining the proper temperature is challenging; controlling the humidity can be energy-intensive. When the humidity is too low, people suffer from cracked skin, nosebleeds, allergy attacks, and general discomfort. High humidity promotes the growth of mold, which can lead to very serious chronic health problems, even death.

1.2 Project Details

1. Establish your stadium geometry.
2. Account for energy sources and sinks:
    a. People generating heat and releasing water vapor
    b. Heat transfer through the roof, especially solar irradiation
    c. Heat transfer through the walls. Use a reasonable facsimilie to represent the walls. With a stadium that is relatively open underneath

(like BDS), the walls would be the concrete structure immediately under the seats. From Figure 1.1, it is easy to see that a sunken stadium like Michigan's "Big House" or one with earthen walls, like those of the Yale Bowl, will have much different heat transfer characteristics than a stadium that is completely above grade.

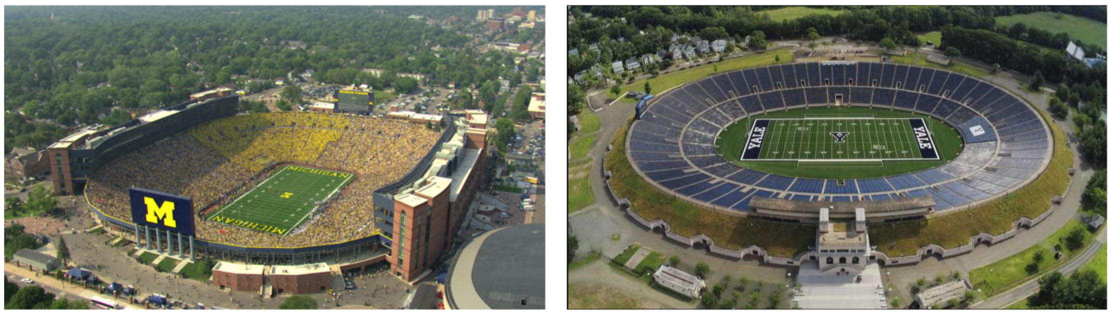

Figure 1.1: Michigan Stadium (L), and the Yale Bowl

d. Keep in mind, an HVAC systems take in air, condition it, then return it to the occupied space. It takes energy to motivate air to move. Moreover, people generally do not like feeling moving air when they are indoors.

1.3 Calculations

1. Develop worst-case scenarios for heating and cooling your stadium, eg, August and February days and nights, and calculate required rates of energy transfer. Outdoor conditions can be found in an almanac or NOAA climactic data.
2. Calculate the power required for an air conditioner or heat pump to meet cooling demands. Determine the cost of said power.
3. Calculate power requirements for a heat pump to satisfy heating demands. Compare heat pump power and cost to those of heating by natural gas and heating by pure electric Joule heating.
4. Calculate the time it takes your HVAC system to reach comfortable conditions, assuming the indoor environment is the same as outdoor ambient conditions.

1.4 Report

coming soon

1.5 Resources

coming soon

Chapter 2

Quick Chill

N05-164, US Navy Request for Proposals

Technology areas
Materials/Processes, Human Systems

Objective
Develop an energy efficient, rugged, shipboard capability to quickly chill a canned beverage product (e.g., soda pop, or “soft drink”) to help eliminate the requirement for operating traditional vending machines at sea.

2.1 Project Summary

For the primary customer on a ship (male, 22 years old), a key Quality of Life (QOL) element as documented by customer surveys is the ability to obtain a cold soft drink from a vending machine. That the per capita consumption of the commodity is almost double the U.S. per capita rate (52 gal a year) testifies to the popularity and desirability of this service. To satisfy this demand, the Navy as part of its QOL programs provides soft drink vending machines on ships. The design of the ship (storerooms separated from selling locations) coupled with the lack of transportation aids and the requirement to have up to 14 machines on larger ships has driven large platforms to devote up to six (6) man-years of effort to keep the machines filled. As the cost of manpower has increased, the need to find alternatives to provide this key QOL product has grown.

The desire is to develop a device capable of chilling a soft drink within 10 seconds, which is estimated to be the upper limit, or customer wait time tolerance, for the beverage consumer. The militarized version of the device needs to be compact and reliable, with little or no in-service maintenance requirements. Such a device, when distributed throughout the shipboard environment, could provide the following benefits:

1. Eliminate, or minimize, shipboard requirements for environmentally threatening use of refrigerants (o-zone deleting substances)

2. Potentially remove all labor requirements involved in the operation of vending machines.

3. Removing the requirement for the product to be chilled at the point-of-sale, enabling more purchasing and storage flexibility to both the retailer (Ship's Store) and the consumer (sailor)

2.2 Background

The rapid chilling of bulk food products (e.g., dairy, fruits & vegetables) and especially solid food (e.g., carcass meat, fresh fish) is a long sought-after industry endeavor that has posted modest advances, with futuristic sights on a capability akin to a "reverse microwave". Restricted by the same heat transfer principles, the objective to rapidly chill a packaged consumer beverage can proceed towards a similar outcome when, and if, technology pushes past the decades-old capability of the vending machine. Rapid chill, with chill-on-demand service, is an evolutionary step away from the trappings of 20th century vending technology.

Consumer appeal for a chill on demand capability is demonstrated in sales of counter-top, household products promising to chill a bottle of wine in six minutes, or a canned beverage in one minute. However, products currently known to be available are extremely limited in applicability, essentially relegated to home use given the need to add both water and ice to the device. Other chill-on-demand technologies include a self-refrigerating beverage can promising to cool 30 °F in three minutes.

While these two examples of technological applications demonstrate the variability in potential approaches for obtaining the desired objective, neither is close to the required shipboard solution (ease-of-use, adequate chilling within 10 seconds). In addition, before any organization will embrace a modern technology, it will determine if the cost of new technology is "affordable" either in acquisition cost or "tradeoff" cost of providing the current service. The shipboard technical requirement exceeds any technology known to be available in the marketplace, and therefore presents unusually high technical risk. For these reasons, some leeway may be accommodated for the desired objective considering the proposed study approaches received.

2.3 Project

Investigate alternative technologies/approaches to rapidly chill aluminum can packaged soft drinks/beverages. Evaluate and document alternatives and a developmental approach for one or more candidate devices.

A promising method is to have a chamber (or chambers) submerged in the drink. In the chamber is a fluid under pressure that will vaporize at atmospheric pressure and normal room temperature. When the chambers are opened, the fluid vaporizes. The Second Law demands the vaporization. The First Law demands the energy required for the phase change to take place. That energy is taken from anything in contact; it cannot be avoided. In this case, the energy is stolen from the soft drink, cooling it. *Yes, this is what causes an aerosol can to get cold when sprayed.*

Other methods abound, but I'm less familiar with how they work. You're free to propose anything feasible. I'm willing to help you sort out your ideas as well.

1. Develop a device capable of chilling a soft drink within 10 seconds.
2. Assume the soft drink is 12 fl. oz. of water.

3. Assume the soft drink is initially 30,°C and must be chilled to 1,°C.
4. Use any of the substances tabulated in any textbook, ASHRAE manuals, NIST, etc.
5. Check for toxicity. I'm no advertising expert, but killing customers seems like it may potentially harm sales.

Chapter 3

Rocket Cryogenic Storage

under construction

Storing Cryogenic liquids is a challenging endeavor. Cryogenic liquids have boiling points that are far below ambient temperature. When storing them, a major challenge is reducing boil-off. The cryogen is under saturation conditions. Any heat transfer into the tank causes some of the cryogen to boil away, a serious concern for applications that requires liquid cryogen (as opposed to very cold gas).

Consider a rocket fueled by liquid methane (LMG), with liquid oxygen (LOX) oxidizer. You are charged with designing the fuel system. We've already determined how much fuel and oxidizer are required to complete the mission. Your major concern is the loss of LMG and LOX while the rocket sits on the pad. You will be launching from the New Mexico desert in mid-June, and the rocket may sit on the pad for up to 2 hours after fueling. Because you're so good at thermodynamics, you know you have several options at your disposal:

1. Increase tank pressure.
2. Insulate the tanks.
3. Load extra cryogens.

3.1 This isn't rocket science...

3.2 ...it's rocket engineering

3.3 Project

1. Size both tanks.
2. Specify the initial masses of LOX and LMG to be loaded into each tank. This is the amount before any boiloff begins.

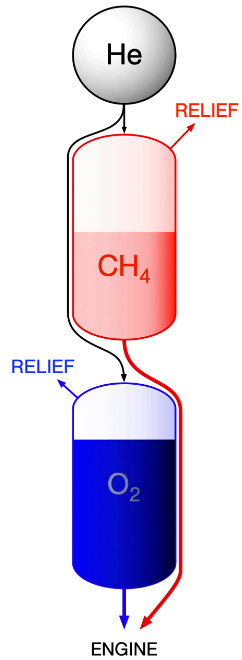

Figure 3.1: Simple depiction of a rocket fuel system

3. Specify operating pressure of each tank.
4. Specify the insulation and its thickness.

3.4 Constraints and requirements

1. It's a rocket. Low weight is holy and just.

3.5 Resources

You may need property data beyond what is in your textbook. Feel free to use other texts, ASHRAE Handbooks, etc. Mathematica has a very nice thermodynamic properties function. The NIST (Linstrom and Mallard, 2019) Chemistry WebBook may be a good option. Find it at webbook.nist.gov.

3.6 Heat Transfer

Chapter 4

Home Energy Audit

under coonstruction

Chapter 5

Stirling Engine

Build a working Stirling engine powered by a candle.

Chapter 6

Waste-to-Energy

under construction

Kill a flock of birds with one rock and a good throw.

Chapter 7

Waste Heat Recovery

under construction

Chapter 8

Writing a *Great* Technical Report

under construction

8.1 Pain, peril, promise

1. Abstract/Summary
2. Pain
3. Attempted solutions
4. Promise
5. Work
6. Results
7. Well...?
8. Now what?

Bibliography

Linstrom, P. and Mallard, W. E. (2019). NIST Chemistry WebBook, NIST Standard Reference Database Number 69.